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Proficiency Analysis of AODV, DSR and TORA Ad-hoc Routing Protocols for Energy Holes Problem in Wireless Sensor Networks

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Abstract

In a densely deployed sensor network, each sensor node senses some event and transmits it to a particular sink via multi hop communications. Sensor nodes deployed nearby the sink node need to convey extra data and control packets, thus undergo much quicker energy depletion rates and therefore have considerably smaller estimated lifespan of network. In the paper, we have analyzed the proficiency of AODV, DSR and TORA protocols in presence of energy holes problem in a wireless sensor network. Throughput, average energy consumption, end to end delay, work efficiency, packet delivery ratio, packet drop rate, nodes alive and routing overhead of each protocol have been demonstrated under different node density. The usefulness of some prevailing approaches towards extenuating this problem has been carried out and simulation results are used to confirm the analysis. It is observed that AODV and DSR protocol outperform TORA in terms of throughput and packet delivery ratio whereas in case of Work efficiency AODV outperforms DSR and TORA protocol. AODV has a smaller amount of end to end delay and average energy consumption as equated to DSR and TORA protocols while Packet drop rate is least in TORA protocol. Routing overhead is lesser in DSR protocol as compared to AODV and TORA. Number of alive nodes in DSR protocol is greater as compared to AODV and TORA.

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Keywords: AODV; DSR; TORA; Energy holes problem; Work efficiency; Energy consumption.

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1. Introduction

A wireless sensor network comprises of an enormous number of sensor nodes densely deployed in an area of interest to collect information and then transmit the data packets to the base station[1]. The sensor networks have large number of applications, such as fire detection, smart home monitoring, data logging, environment (habitat or weather or air pollution) monitoring, industrial and battlefield surveillance[2,3]. The micro sensors are generally back up by battery; therefore these are restricted in resources, can be physical attacked and it is hard to know node deployment scenario. Much of the recent research does not consider the problem of imbalanced energy exhaustion in sensor network scenario with centralized sink. Most of the work has tried to accomplish a uniform and random dissemination to preserve region coverage with the smallest number of sensors. Use of uniform and random scattering in many-to-one sensor nodes network applications causes the sensor nodes nearby the sink node forward more quantity of data and therefore their energy exhaust quicker. As a result, an uneven energy consumption situation reveals itself and energy holes are formed nearby the sink node. If energy holes situation occurs, network fails to send any data to the predetermined sink node. Also, the network lifetime ends rapidly and remaining energy of the nodes would be unused[4-6].

For accurate monitoring, huge number of sensor nodes is arranged in a vast geographical zone. The radio range of the sensor nodes is very restricted therefore network size needs to be increased for complete network coverage. Data transmission to the sink node can possibly be carried out with the support of intermediate nodes. In order to cover different area size various node density has been taken. As wireless sensor network is a type of mobile ad-hoc network protocol (MANET), the execution of MANET routing protocols in WSN should be examined[7].

Wada et al. have shown that when the lifespan of network is finished, most of the energy of nodes is not used, if the nodes are disseminated uniformly in the network[8]. Jia et al.[9] have taken density control and equivalence sensing radius approach to attain stable energy depletion per node. Ma et al. have proposed a non-uniform sensor distribution strategy based on the unequal cluster to diminish energy holes problem[10]. A broad research work has been conducted for energy balance in the existing protocols[9-17]. The measurements and comparisons of the energy depletion behavior of three ad-hoc protocols; Ad-hoc On Demand Distance Vector (AODV)[18], Direct Source Routing (DSR)[19], Temporally-Ordered Routing Algorithm (TORA)[20] have been carried out in[9,11,15-21].

In the paper, the effect of energy holes problem on three protocols i.e. AODV, DSR and TORA have been analyzed by considering the power consumption aspects of the routing protocols using NS-2.34[22,23] simulator. The formulation of the packet delivery ratio versus energy consumption by each protocol has been reported. It is analyzed that which protocol consumes less energy for more packet delivery ratio, i.e. efficiency of a protocol is tested in terms of energy utilization. Further scalability (system ability to perform useful work even if the size of system increases) of network is also considered. Since scalability involves more radio communication bandwidth and energy consumption. We analyzed how these protocols performed with increased load i.e. with high node density using NS-2.34 simulator.

2. Introduction

To accelerate the discussion, the following practical assumptions are made:

- Every sensor node constantly produces constant bit rate (CBR) data and transmits to the sink node via multi-hop shortest routes.
- All sensor nodes are randomly and uniformly disseminated, therefore the node concentration is uniform all over the sensor network:

$$P = \frac{Nodes}{Area} \quad (1)$$

Where Nodes denotes sensor nodes and P denotes density of nodes in the area.

- Transmission range of all sensor nodes is equal.
- All links have sufficient capability to transfer the data.

We have used energy consumption model[24] as follows:

$$E_{TX}(k,d) = \begin{cases} k * E_{elec} + k * \varepsilon_{friss-amp} * d^2, d < d_o \\ k * E_{elec} + k * \varepsilon_{two-ray-amp} * d^4, d \geq d_o \end{cases} \quad (2)$$

$$E_{RX}(k) = E_{elec} \times k \quad (3)$$

Where E_{TX} and E_{RX} are energy consumed in transmission and receiving of a data packet respectively.

- Data rate of every single sensor node is given by k (in bits/sec). When the distance d is relatively far-away, the multiple-path fading channel model (d^4 power loss) is used otherwise free space model (d^2 power loss) is used.
- E_{elec} is the radio energy dissipation, used to activate the transmitter and receiver circuit board.
- ε_{fs} and ε_{amp} are amplifier energies, the energy required by power amplification to achieve an acceptable bit error rate in the two models.
- The distance d_0 is a threshold value known as a cross-over point[24].

When nodes start transmission of packets to the predetermined sink node, nodes available adjacent to the sink node have to send their data, control packets and simultaneously forward the data, of other nodes which are far from the sink. So nodes adjacent to the sink start depleting their energy quicker than other nodes as presented in Fig. 1(a) where node 0 is a sink node.

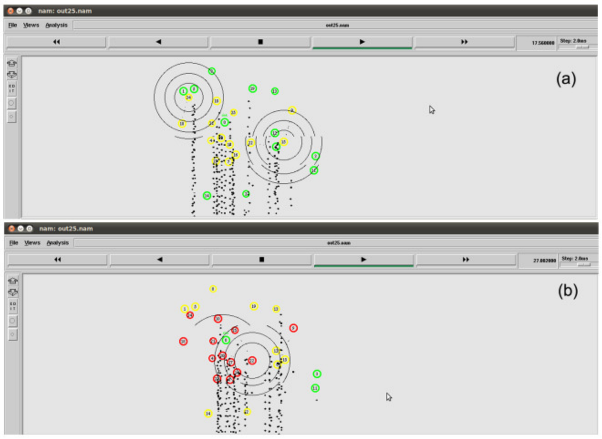

Fig. 1. (a) Energy consumption pattern of 25 nodes with time; (b) Energy holes creation near sink node and increased packet drop rate first picture.

With time energy of nodes which are near the sink exhaust and they are not able to transfer more data packets therefore nodes left with sufficient energy are also not capable to transmit their data packets towards the sink as shown in Fig 1(b). This situation is called energy holes problem. This result in to lower throughput, more end to end delay and higher packet drop rate increases. Nodes are still alive in the network but their energy is of no use as they are not capable to send the data packets to the sink. It is evident from Figure 1 and 2 that out of 25 nodes, 14 nodes with sufficient energy are still alive at the end of network simulation, i.e. energy of all nodes could not be used, this is called unbalanced energy utilization. Energy holes problem leads to low throughput and increased end to end delay and higher packets drop. So we have analyzed three protocols in provisions of average energy consumption, throughput, packet delivery ratio, routing overhead, end to end delay and work efficiency in the presence of energy holes problem and different node density.

3. Wireless Ad Hoc Routing Protocols

3.1. AODV

The Ad-hoc On-demand Distance Vector routing protocol[18] is a reactive protocol which does not keep global routing information for the entire network, therefore routes are formed on demand. If nodes are not part of a route then they do not need to maintain any information for that route. Nodes do not transmit or receive topology-update information packets; hence they have information only for their live routes. A route is considered live by a node, if node can transmits, accepts or advanced packets for that route with in a stable time period. Therefore in the AODV protocol, when a source node wishes to communicate with a proposed destination and it does not have a valid route towards the destination, route finding packets known as RREQ are commenced and broadcasted. Any change in network topology scenario must be sent using Route reply message (RREP), merely to those nodes that will require this info. Therefore, AODV vigorously creates entries in the route table. In case of link failure a routing error message (RERR) is used for link failure notification and a HELLO message is used for link detection. Asymmetric links are not maintained by AODV protocol. The main benefit of AODV protocol is that on demand routes are created and destination sequence numbers are used to detect the up-to-date route toward the particular destination. The association setup delay is less. The routes conservation HELLO messages are range-limited, so they do not cause needless overhead in the network.

3.2. DSR

The Dynamic Source Routing protocol[19] permits sources to find out paths to any destination. Before arriving at desired destination, all data packets of source include an entire list of nodes, which the packets must go through. Therefore, all nodes that advanced or listen in these packets may collect routing info for further use. In addition to assist rapid network topology transforms, DSR protocol also provide asymmetric links. Furthermore, like AODV, DSR has a route finding process if a route is not set up. Source flood RREQ in the network and destination on receiving the first RREQ packet sends a RREP towards Source. DSR provides on demand route conservation; hence no regular update packets are required for topology changes. Upon link failures, merely nodes that advanced packets through failed links must have accurate advertisements for routing. Furthermore, DSR permits sources to obtain and reserve more than one path to a specific destination in a cache. When a link failure is informed midway nodes have the chance to choose another cached route.

First of all source nodes examine that they have a route in their cache for a particular destination. If a route exists, source node will use that route by inserting the sequence of hops in data packet header. If this kind of route does not exist in the local cache of the node, then the source node will start a fresh path finding procedure with a RREQ, as explained above. DSR is valuable in network with low mobility since the routes kept in the route cache will be useable for extended time. Furthermore no periodic beaconing is required in DSR, so nodes can go in sleep node to preserve their energy.

3.3. TORA

Temporally-Ordered Routing Algorithm is a dispersed and loop-free process which works well in dynamic network. TORA rapidly offers several routes, using fewer routing overhead, via confining the creation of routing messages to individual stations positioned adjacent to the topological modifications[20]. Every station requires information of its one-hop neighbors merely. This shows the disseminated behavior of the TORA protocol. The protocol contains process of route finding, conservation and removal. Consider a network using N number of nodes denoted by a graph $WSN = (N, U_L)$. All undirected symmetric links (m, n) are confined in U_L. For a sensor node m, a set of neighbor nodes *NBR* $\in$ *graph*, is available specified as $(m, n) \in U_L$. Whenever topological alterations lead to link failures, route reinstatement is done through certain temporally ordered computations. TORA find out routes on demand; though the foremost objective of the protocol is to form routes rapidly, whereas discovery of the shortest path is of lesser significance. When a source node desires to transmit data to a proposed receiver, node starts a Request message in which node contains the specific destination node address. Further destination node, or a midway receiver node of request message for a route to specific destination, will answer with an Updated packet. Every station which receives this Updated packet changes its height parameter to a certain value higher than the one confined in the packet. Therefore, a unique set of consecutive directed links is formed.

The key benefit of TORA protocol is that it has lowered the pervasive control messages to a set of adjacent nodes, whenever a topology amendment has happened. The drawback of TORA is that it may create temporary unacceptable routes.

4. Simulation and Results analysis

4.1. Simulation

The network scenario has been designed and implemented using Network Simulator NS2.34. The simulator executes AODV, DSR and TORA protocols to measures the performance of network in terms of packet delivery ratio, end to end delay, throughput, routing overhead, average energy consumption and work efficiency. All the sensors (excluding the sink node) are homogeneous in terms of initial energy as shown in TABLE 1. In simulation, node density 15 to 100 has been taken since higher node density leads to increase in number of connections and traffic load in network and thus affect the performance of protocols. When a sensor node transmits or receives a data or a control packet, the reduction in the node's energy depends on the size of the packet, bandwidth used and precise NIC features. Energy is consumed by the equipment during data transmission, reception and listening. In our model, we have not considered energy consumption during the listen operation because node is idle at that time and every ad hoc routing protocol will consume equal energy. For the packet propagation, the Radio Frequency (RF) propagation model is used; RF signifies the percentage of the energy consumed when a packet is transmitted, decides energy level with which the adjacent node's interface receive the packet and decide for successful packet reception.

Table 1. Network Simulation Setup .

Simulation Time	Simulation Area	Node Mobility	Traffic Type	Propagation	Mac Layer Protocol	Size of packet	Packet Rate	Node Density	Initial Energy of sensor nodes	Initial energy of sink node	Power consumption in receiving mode	Power consumption in transmitting mode
100 sec	1500m * 1500m	No	CBR	Two Ray Ground	802.11	512 byte	300 Kbps	25,35,50,75, 100	10 J	20 J	0.3 mJ	0.9 mJ

4.2. Results analysis

In Fig. 2(a) the sensor network's average throughput is provided for AODV, DSR and TORA routing protocols. Average throughput (in bits/second) is expressed as the proportion of the whole quantity of data that arrives at receiver from a sender to the period taken by the receiver to acquire the last packet. Aspects that influence throughput metric comprise numerous topology fluctuations, restricted bandwidth, unreliable communication, and restricted energy.

It is evident from Fig. 2(a) that for smaller number of nodes throughput of AODV and DSR is higher than TORA and reduced with the increase in node density. In case of 25 nodes scenario, substantial difference of throughput is perceived because significant overhead to reroute the packets increases in TORA. If number of node increases above 25, TORA upturns IMEP's neighbor finding process and creates several routes. Consequently, network is flooded with more routing overhead and throughput of TORA is reduced. AODV performance is better as the rate of receiving data packets by AODV is higher. However throughput reduced as number of nodes increases for all three protocols because the packet drop rate is higher for higher node density. During the period of route discovery, on demand ad-hoc protocols like DSR and AODV drop a significant quantity of packets because route attainment takes time proportionate to the distance *d* among source node and specific destination node. TORA is relatively subtle to the loss of routing packets in contrast to other ad-hoc protocols.

Fig. 2(b) shows the effect of node density on packet delivery ratio of AODV, DSR and TORA protocols. The Packet Delivery Ratio (PDR) indicates the efficiency of a protocol in delivering packets from source sensor nodes towards the sink node. This measure describes inclusiveness, accuracy and consistency of routing protocol

$$Packet\ Delivery\ Ratio = \frac{Total\ Packets\ received\ by\ the\ destination\ node}{Total\ Packets\ sent\ to\ destination\ node} \times 100 \tag{4}$$

It is observed from Fig 2(b), DSR has higher Packet delivery ratio for higher node density as compared to AODV protocol as DSR always looks for the most fresh and reliable route when needed and does not search from the routing table like AODV. Therefore DSR delivers packets accurately. All three protocols have reduced PDR when node density is increased or we can say that PDR decreases when scalability increases.

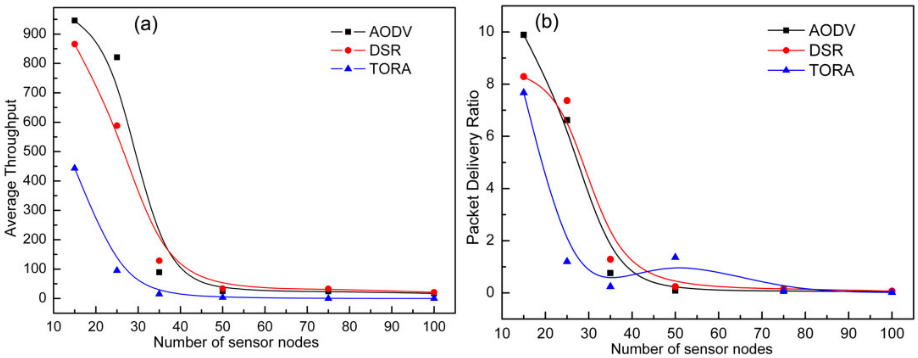

Fig. 2. (a) Variation in Average throughput using different node density; (b) Influence of different node density on packet delivery ratio for AODV, DSR and TORA protocols.

The overall effect of scalability is more acute on TORA protocol. With packet size 512 bytes, TORA is not capable to route such quantity of traffic, as a result TORA drops main portion of the packets and collapses to coincide because of amplified congestion. The reason behind the packet drop is that TORA is surfaced above Internet MANET encapsulation protocol[25]. IMEP gives warning to TORA whenever a link to one of its neighbor node is formed or damaged. A positive feedback loop formed in TORA over IMEP causes the congestive breakdown. The amount of routing packets transmitted triggers frequent collisions in the MAC layer; this becomes reason of loss of HELLO, data and ACK packets. Consequently IMEP incorrectly consider that links to its adjacent nodes are malfunctioning, accordingly TORA start sending more number of UPDATEs in response of apparent link malfunctioning that results in to additional congestion. Furthermore all UPDATEs entail reliable delivery and increase the expose to extra inaccurate links failure discoveries. The failure to accept an ACK packet from retransmitted UPDATE messages becomes a link break sign. Routing overhead information in Fig. 3(b) shows that the terrific increase in routing packets is also accountable for the congestion. TORA is incapable to recover from the positive feedback loop for big packet size, even when all nodes are stationary. Therefore in general DSR scales superior than AODV and TORA in terms of PDR.

The end to end delay of sensor network is measured for AODV, DSR and TORA protocol in Fig. 5 for different node density. End to end delay is the time interval between arrivals of data packet at the destination minus the period the data packet is sent by the source node.

As shown in Fig 3(a), it has been observed that average end to end delay is greater in TORA and DSR as compared to AODV protocol and increases with node density. AODV routing table has simply one route per destination, which is constantly updated based on the sequence number. Nodes will wait in the interface queue until routing protocol finds valid route to the sink node. The delay period is influenced by route finding process which is the first stage in a communication process. The average end to end delay of AODV increases up to 50 nodes. This expansion can be rationalized by the supplementary bandwidth exhausted by the data or control packets (Request to send, Clear to Send) that are dropped, along with the added routing packets. These packets can be retransmitted repeatedly, owing to collisions or link loss. In DSR protocol a node uses a route to the access point until route's disruption. Sometime this route can be quite long, but node carries on sending the data packets beside the lengthy route to the access point until the route is discontinued. Consequently, for these data packets end-to-end delay rises, resulting in amplified average end-to-end delay for all data packets. DSR has a lengthier delay than AODV because its route finding takes longer time because each midway node extracts information before forwarding the reply. DSR make route discovery more gainful because each intermediate node has route information but it increases delay in transmission of packets.

TORA has most awful delay feature because of loss of facts and data with distance. Route creation in TORA consumes too much time that leads to extended delay while waiting for fresh route. TORA has more delay than DSR because TORA does not have faster route discovery process as in case of DSR. In case of congestion TORA responses severely, which causes TORA to fall a main quantity of traffic. In case of high node density or higher traffic load, DSR control message gets lost. So end to end Delay of TORA and DSR is higher than AODV. Fig 3(b) presents effect of node density on Routing overhead caused by AODV, TORA and DSR routing protocols. Routing overhead represents the complete number of routing packets communicated. It does not contain medium access control or address resolution protocol packets. Every protocol has different routing overhead because every routing protocol can be executed for dissimilar MAC or ARP protocols. The routing overhead computes the amount of work done by the protocol for network including numerous nodes, low bandwidth or in full load situation. For higher routing overhead, number of routing packets is more and the efficiency of the protocol is lower in terms of bandwidth utilization.

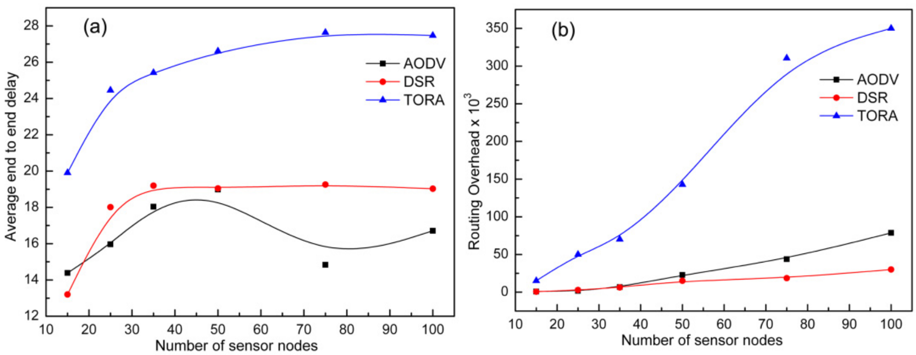

Fig. 3. (a) Variation in Average end to end delay for different number of sensor nodes; (b) Variation in Routing Overhead for routing protocols AODV, DSR and TORA with different node density.

The routing packets provides information about processing capability of the ad-hoc protocols in networks with low-bandwidth, high density and full load. TORA generates substantial quantity of control packets, specifically after 50 nodes since there are several working routes to be sustained. Being a reactive protocol AODV adds less overhead to the protocol stack as compared to TORA which is an adaptive protocol. In AODV, as number of nodes increases, networks flooded with RREQs and RREPs. Routing table will not keep routing overhead if the best route from source to destination has been selected. This decreases the amount of routing overhead in an AODV implemented network and results in to enhanced network throughput and increased packet delivery ratio. Extreme routing overhead obstructs data packets from arriving at their destinations. For high node density, DSR outperforms both AODV and TORA, because it has lesser routing overhead than AODV and TORA.

Packet drop rate for network is evaluated in Fig. 4(a), among three protocols, TORA has minimum packet drop since it rapidly provides multiple routes. Every node needs data about its one-hop neighbors only. Such dispersed operation of TORA, provides many routes to a destination. DSR and AODV protocols drop a substantial amount of packets throughout the route finding phase. Proficiency of the protocols is greatly dependent on storing of data packets during route finding stage. AODV has a marginally lesser packet delivery proficiency than DSR because of more packet drop rate. It has been observed from Fig. 4(b) that average energy consumption of the routing protocols AODV, TORA and DSR increases with number of sources increases. Average Energy consumption is the proportion of sum of entire energy used up by every node to the entire number of nodes.

$$Average\,Energy\,Consumption = \frac{\sum_{i=1}^{n}\left\{Initial\,energy\left(x_i\right) - Final\,energy\left(x_i\right)\right\}}{Total\,Number\,of\,Nodes} \tag{5}$$

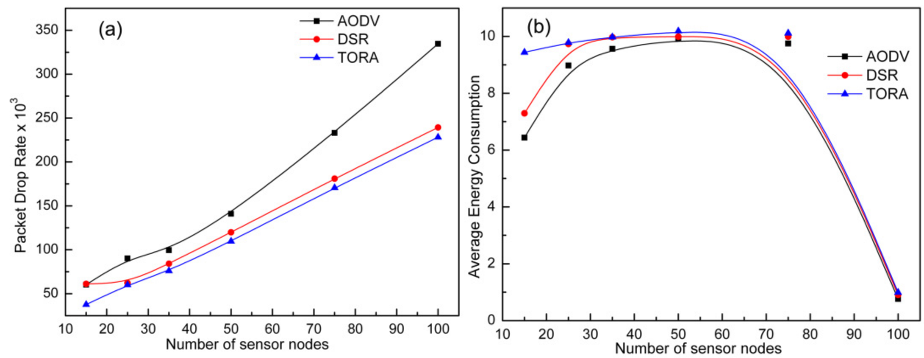

Fig. 4. (a) Packet Drop Rate vs. number of sensor nodes; (b) Average Energy consumption vs. number of sensor nodes for AODV, DSR and TORA protocols.

The total consumption of energy is highly associated with the transmission process, which includes transmission of node's own data and neighbor node's data. In terms of routing packets the energy consumption, AODV and DSR protocols performs superior than TORA protocol since routing packet overhead is higher in TORA as compared to AODV and DSR. Since AODV has least average energy consumption, nodes in the network survive for longer time, thus there is increase in lifetime and throughput of the network. In the set-up, all the nodes are stationary and transmitting data simultaneously and there is no frequent topology change.

With energy holes problem routes are lost when energy of nodes finish and therefore these nodes do not belong to any route. In case of AODV, nodes that are not part of a route do not sustain info for that route and therefore do not transmit or accept topology-update information packets. Therefore, from the results it has been observed that for energy holes problem AODV perform better than DSR and TORA, for lower density of nodes variation in energy consumption is significant.

In DSR protocol a source node that wishes to transmit data to a certain destination, examine for a path in its cache for that particular destination. On finding the route, source will use that route and packet followed the route to reach that particular destination. However if no such path exists in storage of the cache, then the source node will commence a new path exploration method, by disseminating a Route Request in its zone. In case of energy holes problem most of the nodes adjacent to the sink has no energy. So when energy holes emerge, DSR has to replace most of its cache entry and will start a new path finding process which in turn results in to more energy consumption. In case of TORA protocol the maintenance packets and aggregation of IMEP path finding routes packets cause high-energy consumption.

Fig. 5(a) illustrates work efficiency of network provided for AODV, DSR and TORA protocols. Work efficiency is formularized as ratio of PDR and Average energy consumption. It is used to analyze efficiency of a protocol i.e. if a protocol consumes less energy and produces more PDR, it is more efficient than a protocol which consumes less energy and produces less PDR.

$$Work\,Efficiency = \frac{Packet\,Deliver\,Ratio}{Average\,Energy\,Consumption} \tag{6}$$

It has been observed that for smaller number of nodes AODV performs better than DSR and TORA but as number of nodes increases from 15 to 35 DSR becomes better than AODV and TORA. For 50 nodes TORA has best results due to lower packet drop rate. However for higher node density all the three protocols have nearly same work efficiency. Therefore it has been determined that AODV and DSR protocols are superior in comparison with TORA protocol.

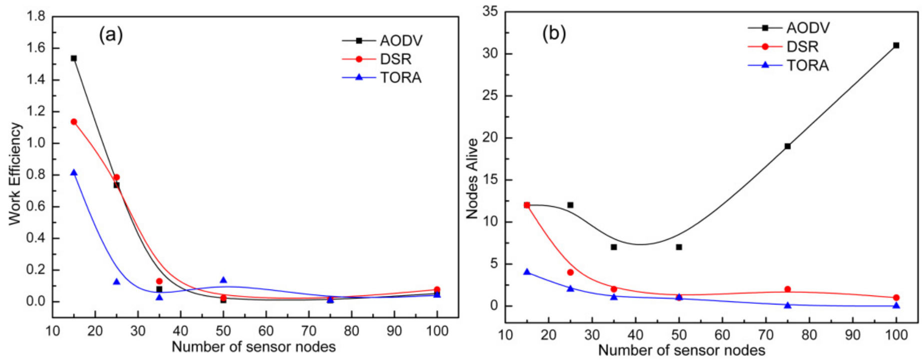

Fig. 5. (a) Work Efficiency vs. number of sensor nodes; (b) Number of nodes alive in the network for AODV, DSR and TORA protocols.

It has been observed from Fig. 5(b) that number of nodes alive is much higher for AODV protocol as compared to DSR and TORA protocols. Number of nodes alive illustrates network lifetime. It is the time between the start and end of the network operation of operation. A network operation ends when all the nodes completely deplete their energy. It is desirable that nodes work for longer time. Therefore network lifetime is measured by the number of nodes alive per round. If there are many alive nodes in the network, it works for longer period of time. So it is evident that AODV has maximum network lifetime.

5. Conclusions

Simulation of wireless sensor network has been carried out successfully with NS-2.34 simulator with AODV, DSR and TORA as the ad-hoc routing protocols. The network has been set up for different node density to test the proficiency of these routing protocols under different work load. AODV and DSR succeeded to manage the higher load, although higher numbers of packets were dropped. On the contrary TORA was incapable to route that extent of traffic and produced terrific volume of routing packets. The reason of the congestion breakdown lies apparently in a positive feedback loop between the thrashing of data packets and the formation of routing packets. These interpretations lead us to conclude that TORA most undoubtedly would not be appropriate for networks with high density nodes or full load. It is also evaluated that how three protocols performs in the presence of energy holes problem. DSR proved to be a reliable choice where work efficiency is concerned. AODV and DSR maintained higher PDR due to their on demand nature and their fast recovery when the nodes were depleting their energy. However in case of average energy consumption, number of nodes alive and average end to end delay AODV outperforms other two protocols.

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References

1. Akyildiz IF, Su W, Sankarasubramaniam Y, Cayirci E. A survey on sensor networks. *Commun Mag IEEE* 2002, **40:**102-14.
2. Li Y, Thai MT. *Wireless sensor networks and applications*: Springer Science & Business Media; 2008.
3. Raghavendra CS, Sivalingam KM, Znati T. *Wireless sensor networks*: Springer Science & Business Media; 2004.
4. Olariu S, Stojmenovic I. Design Guidelines for Maximizing Lifetime and Avoiding Energy Holes in Sensor Networks with Uniform Distribution and Uniform Reporting. In: *INFOCOM*; 2006. p. 1-12.
5. Liu A, Liu Z, Nurudeen M, Jin X, Chen Z. An elaborate chronological and spatial analysis of energy hole for wireless sensor networks. *Comput Stand Inter* 2013, **35:**132-49.
6. Wu X, Chen G, Das SK. Avoiding energy holes in wireless sensor networks with nonuniform node distribution. *IEEE T Parall Distr* 2008, **19**: 710-20.
7. Kassim M, Rahman RA, Mustapha R. Mobile ad hoc network (MANET) routing protocols comparison for wireless sensor network. In: *System Engineering and Technology (ICSET), 2011 IEEE International Conference on*: IEEE; 2011. pp. 148-52.
8. Wadaa A, Olariu S, Wilson L, Eltoweissy M, Jones K. Training a wireless sensor network. *Mobile Netw Appl* 2005, **10:**151-68.
9. Jia J, Chen J, Wang X, Zhao L. Energy-balanced density control to avoid energy hole for wireless sensor networks. *Int J Distrib Sens N* 2012, **2012**.
10. Ma G, Tao Z. A Nonuniform Sensor Distribution Strategy for Avoiding Energy Holes in Wireless Sensor Networks. *Int J Distrib Sens N* 2013, **2013.**
11. Ng K-P, Tsimenidis C. School of Electrical and Electronic Engineering, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK. In: *Wireless Sensor (ICWISE), 2013 IEEE Conference on*: IEEE; 2013. p. 36-41.
12. Tripathi J, De Oliveira JC, Vasseur J. Proactive versus reactive routing in low power and lossy networks: Performance analysis and scalability improvements. *Ad Hoc Netw* 2014, **23:**121-44.
13. Razouqi Q, Boushehri A, Gaballah M, Alsaleh L. Extensive Simulation Performance Analysis for DSDV, DSR and AODV MANET Routing Protocols. In: *Advanced Information Networking and Applications Workshops (WAINA), 2013 27th International Conference on*: IEEE; 2013. pp. 335-42.
14. Pragadeeswaran G, Ezhilarasi D, Selvakumar P. A Performance Analysis of TORA, AODV and DSR Routing Protocols in MANET using NS2. *Int J Sci Eng Res* 2012; 3: 1-5.
15. Bella G, Costantino G, Crowcroft J, Riccobene S. Enhancing DSR maintenance with power awareness. *Comput Stand Inter* 2013, **35:**107-13.
16. Saleem M, Ullah I, Farooq M. BeeSensor: An energy-efficient and scalable routing protocol for wireless sensor networks. *Inform Sci* 2012, **200:**38-56.
17. Radwan A, Mahmoud T, Houssein E. Evaluation comparison of some ad hoc networks routing protocols. *Egypt Infom J* 2011, **12:**95-106.
18. Perkins CE, Royer EM. Ad-hoc on-demand distance vector routing. In: *Mobile Computing Systems and Applications, 1999. Proc. WMCSA'99. Second IEEE Workshop on*: IEEE; 1999. p. 90-100.
19. Johnson DB, Maltz DA. Dynamic source routing in ad hoc wireless networks. In: *Mobile computing*: Springer; 1996. p. 153-81.
20. Park V, Corson MS. Temporally-ordered routing algorithm (TORA) version 1 functional specification. In: Internet-Draft, draft-ietf-manet-tora-spec-00. txt; 1997.
21. Alotaibi E, Mukherjee B. A survey on routing algorithms for wireless Ad-Hoc and mesh networks. *Comput Netw* 2012, **56:**940-65.
22. Fall K, Varadhan K. The NS manual, the VINT project, UC Berkeley, LBL, USC/ISI, and Xerox PARC. In; 2008.
23. Issariyakul T, Hossain E. *Introduction to network simulator NS2*: Springer Science & Business Media; 2011.
24. Heinzelman WB, Chandrakasan AP, Balakrishnan H. An application-specific protocol architecture for wireless microsensor networks. *IEEE T Wirel Commun* 2002, **1**: 660-70.
25. Corson MS, Papademetriou S, Papadopoulos P, Park V, Qayyum A. An internet MANET encapsulation protocol (IMEP) specification. In: Internet-Draft, draft-ietf-manet-imep-spec-01. txt; 1998.